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FUNGICIDAL DUSTS FOR THE CONTROL OF BUNT

BY

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(Based on investigations conducted under coöperative agreement between the Office of Cereal Investigations, of the Bureau of Plant Industry, United States Department of Agriculture, and the University of California Agricultural Experiment Station.)

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By WILLIAM W. MACKIE and FRED N. BRIGGS

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FUNGICIDAL DUSTS FOR THE CONTROL OF BUNT OR STINKING SMUT OF WHEAT

Bunt, or stinking smut, has long been recognized as a destructive disease of wheat. Its control, however, was not undertaken in a scientific or effective manner until about the middle of the last century, when Kühn[18] began his classic experiments on the effect of copper sulfate on the spores of the bunt fungus. Although effective remedies for control of bunt have been found in the use of bluestone (copper sulfate and formaldehyde), their universal application has not been practiced for the following reasons:

1. Bluestone solutions of sufficient strength to destroy the bunt spores kills the wheat germ, or so affects it that the growth of the primary roots are delayed or the plumule is distorted and weakened.

Forty to 60 per cent of the wheat treated by bluestone on our California farms never comes up. Solutions which do not injure the germ are too weak to prevent bunt infection.

2. The dipping of bluestone-treated wheat in a lime solution prevents the greater portion of the bluestone injury, but has the dis-

Fig. 1.—No. 5, bunted White Australian head and bunt gall. No. 6, normal White Australian head and kernel. Natural size. Under competitive field conditions bunt attack reduces the size of the plant, head and kernel.

advantages of extra cost in labor and time. The additional costs could be borne if this were all, but frequently heavy losses of seed treated by the bluestone-lime method have occurred when such seed has been stored too wet. When seed is properly dried, as usually is the case with seed treated early in the fall before the rainy season

is far advanced, no injury from heating or fermentation occurs. But when weather conditions force the farmer to store seed too wet, the lime coating prevents proper drying, and seed losses may follow.

3. Formaldehyde is an effective remedy against infection from seed-borne spores of the bunt fungus and several other smuts of cereals, but it, too, is limited by its destruction of seed germs under certain climatic conditions, as has been conclusively shown by investi-

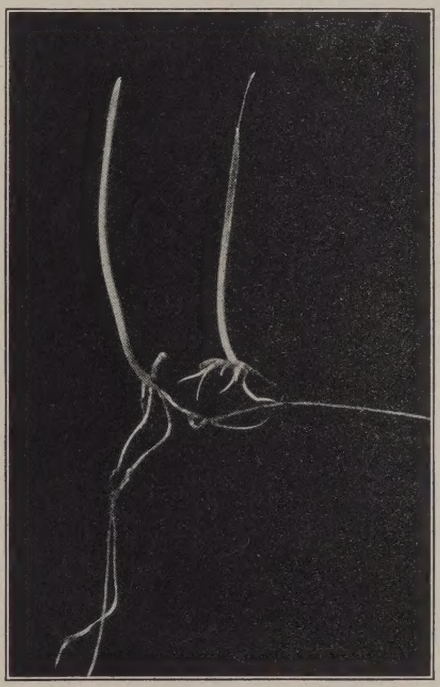


Fig. 2.—Root development retarded by bluestone. Normal seedling to left. Seedlings with delayed root development frequently die. In others, delayed growth and maturity result.

gations in California.[17, 21] The experience of farmers in California and other semi-arid regions[6] positively shows that seed injury results from formaldehyde-treated seed either when stored dry for a period of more than 48 hours before seeding or when seeded into soil too dry to cause immediate germination. This injury is seen in destroyed germs, distorted plumules, and weakened seedlings. Instances have been recorded in California where thousands of acres sown with

formaldehyde-treated seed failed to produce even a poor stand. Owing to the necessity of California farmers having to sow much of their summer fallowed lands before the rainy season begins, formaldehyde cannot be used without liability to severe seed injury.

4. The loss of time at the busy seeding period tends to prevent seed treatment. It has been shown by von Tubeuf[29] that seed from a crop with only one or two per cent of bunt showing no visible spores may in the following crop produce 20 to 30 per cent of smutted plants. Seed treatment, therefore, should be practiced every year whether bunt appears to be present or not.

In order to induce the farmer to treat his seed wheat for bunt every year, the difficulties presented in the use of solutions of bluestone, bluestone and lime, and formaldehyde, must be obviated. An effective fungicide, which can be applied to seed long in advance of seeding operations, and which will not injure seed germs even in the hands of careless farm help, must be provided if universal control of bunt is to be attained. The copper carbonate dust method of seed treatment appears to meet these requirements. The results of three years' experiments and tests to determine the effectiveness as well as the limitations of copper carbonate dust when applied to bunt-infested seed are here presented in support of this new method of seed treatment.

EARLY EXPERIMENTS WITH CHEMICAL DUSTS FOR THE CONTROL OF BUNT

Farmers always have desired a dry fungicide because of the difficulties and costs connected with the use of liquid preventives. Lime, either burnt or air-slaked, has long been applied as a powder, but ineffective control of bunt has prevented its acceptance. Bolley[3] tried many dry processes, testing among others "dry powdered formaldehyde mixed with chloride of lime and flowers of sulfur, and suggests that extended research might develop a satisfactory dry method. His own experiment gave little or no bunt control, and much seed injury.

Copper carbonate dust as a smut fungicide was used by von Tubeuf in 1902,[29] who treated heavily bunted seed with copper carbonate dust and secured only 1.7 per cent of bunted heads. At the same time untreated seed gave 29.3 per cent, while Bordeaux powder gave 14.9 per cent. No reason is given why the use of copper carbonate dust was not continued. Darnell-Smith[7, 8, 9, 11] experimented

with heavily bunt-infected seed at Cowra and at Wagga in New South Wales in 1915 and later. He secured better results in bunt control and seed germination with copper carbonate dust (2 ounces per bushel) than with standard methods. Following the success of Darnell-Smith, preliminary experiments with copper carbonate dust were made at Berkeley and Davis[22, 23] in 1920. These experiments were highly encouraging, but were limited owing to late seeding (March 8 and April 9). During the years 1921 and 1922, a large number of experiments were conducted at Davis. Care was taken to check, with many duplications, all dust treatments with the standard bluestone and formaldehyde treatments. Because of the large number of experiments conducted, it has been found necessary to present these results in averages.

PLAN OF PROCEDURE

A method of seed treatment so new, and presenting so many obvious practical advantages if successful, must of necessity be tried out under the most rigid tests. The following methods, therefore, were followed in the two years' trials at Davis.

1. The bunt spores were grown during the preceding year and consisted only of spores of *Tilletia tritici* (Bjerk.) Wint.

2. As previous experiments had been rendered inconclusive by irregular smut infection, a graduated scale of bunt spore dosage was used. Before the seed was treated with the fungicide, each lot was dosed with a given weight of bunt spores to a given weight of wheat seed, as follows:

Grades	Bunt Spores in Grams	Wheat Seed in Grams
1	1	30
2	1	250
3	1	500
4	1	750
5	1	1000
6	1	1500
7	1	2000
8	1	2500
9	1	3000

3. Little Club wheat, highly susceptible to bunt (pl. 3), but very resistant to lodging and shattering, was used in 1921. Because of its late maturity and susceptibility to stem rust, it was replaced in 1922 by White Federation, an equally bunt-susceptible but much earlier variety and fairly resistant to lodging and shattering.

4. The quantity of chemical dusts applied to the seed was graduated into four rates, except flowers of sulfur, for which greater quantities were used.

5. The plots were arranged in rows separated by a space of one foot. The seed was accurately weighed so as to give 150 ± 2 kernels per rod row.

Fig. 3.—No. 1, bunted Little Club and bunt gall (natural size). No. 2, normal Little Club head and kernel. Bunted Club wheat shows reduced thickness of head.

6. Because both plants as well as heads were to be counted, the seeds were dropped by hand and spaced at an average distance of 1⅓ inches. As approximately 50 per cent of the seed fails to produce plants in the soil at Davis, the harvested plants were separated on the average by more than 2½ inches, thus making possible an accurate separation of the plants at harvest time. To prevent breaking of plants, the soil was softened by irrigation previous to pulling.

INFLUENCE OF SPORE LOAD UPON BUNT ATTACK

Field observations supported by counts of bunt spores on seed wheat indicate that the number of spores per kernel decidedly influence the bunt attack. Seed carrying no more than ten spores on each kernel has not been observed to give infection.

The seed for the 1921 crop was separated into nine lots, according to the quantity of bunt spores applied. The dosage by weight ranged from 1 part of bunt spores to 30 parts of seed wheat (1–30) to 1 to 3000 parts (1–3000). This last, or lightest dosage, yielded several hundred bunt spores per kernel (pls. 1 and 2).

The effect of variation in the dosage of bunt spores on seed is shown in table 1.

TABLE 1

SUMMARY OF BUNT ATTACK ACCORDING TO THE DOSAGE OF SPORES. Experiments Conducted During 1921 and 1922 at Davis

Per Cent of Bunt by Head Count

	Spore Dosage to Seed by Weight								
	1–30 Bunt per cent	1–250 Bunt per cent	1–500 Bunt per cent	1–750 Bunt per cent	1–1000 Bunt per cent	1–1500 Bunt per cent	1–2000 Bunt per cent	1–2500 Bunt per cent	1–3000 Bunt per cent
Average 1921.....	61.6	37.3	37.0	28.7	20.7	16.3	16.1	10.6	10.3
Average 1922.....	36.8	41.4	45.5	39.6	25.7	31.9	21.0		

These results show that the bunt attack is reduced as the dosage is decreased. The influence of spore dosage upon the effectiveness of various chemicals is very marked and conforms generally to the scale of bunt reduction shown in table 1. The scale of spore dosage is therefore conducted as an essential part of every set of experiments with fungicidal solutions or dusts. These results agree closely with those secured by Heald, at Pullman, Washington,[15] whose researches caused him to believe that an accurate prediction of the possible bunt per cent in a crop can be made from determination of the number of spores on the seed sown.

CONTROL OF BUNT BY SOLUTIONS OF STANDARD FUNGICIDES

Standard solutions previously proven effective in preventing infection from seed-borne spores were used as checks for comparison wherever fungicides in the dust or powder form were being tested.

TABLE 2

RELATIVE EFFECTIVENESS OF STANDARD FUNGICIDAL SOLUTIONS IN PREVENTING BUNT INFECTION UNDER VARYING DOSAGES OF SPORES IN EXPERIMENTS CONDUCTED AT DAVIS

Per Cent of Bunt by Head Count

Treatment	SPORE DOSAGE TO SEED BY WEIGHT								
	1–30 Per Cent Bunt	1–250 Per Cent Bunt	1–500 Per Cent Bunt	1–750 Per Cent Bunt	1–1000 Per Cent Bunt	1–1500 Per Cent Bunt	1–2000 Per Cent Bunt	1–2500 Per Cent Bunt	1–3000 Per Cent Bunt
Check (Untreated)	49.2	39.3	41.2	34.1	23.2	24.1	18.5	10.6	10.3
Bluestone (1-5) 3″	2.5	1.1	.4	.8	.3	0.0	.1	0.0	0.0
Bluestone (1-4) 3″ + Lime (1-8) 5″	.7	.8	.6	.2	.1	.1	.1	.1	0.0
Formaldehyde (1-40) 10″	1.1	1.2	.2	.2	0.0	.1	.1	.1	.2

All three of the standard fungicidal solutions are shown to be practically completely effective when properly applied even for the very heaviest dosage of bunt spores used in these experiments. It remains, therefore, to compare the effectiveness of fungicidal dusts and powders with the fungicidal solutions.

EFFECT OF FLOWERS OF SULFUR ON THE CONTROL OF BUNT

Farmers from time to time have reported successful control of bunt by means of flowers of sulfur. To test the efficacy of this dust, exhaustive experiments were conducted at Davis in 1919, 1920 and 1921. The experiments in 1919 indicated that sulfur was not fully effective against infection when the seed was blackened with bunt. The experiments in 1920 showed that sulfur and seed wheat mixed and drilled at the rate of 25 pounds of flowers of sulfur to 100 pounds of seed reduced bunt to one-tenth (61.8 per cent to 6.3 per cent), but in no case eliminated it. Sulfur produced no effect in preventing infection from spores already in the soil.

In order finally to determine the limitations of flowers of sulfur as a bunt fungicide, 135 tests with this dust were made at Davis in 1921. The usual rod-row method was employed. The dosage of bunt

spores applied to the seed was arranged in nine lots, varying from 1–30 to 1–3000 by weight. The results of these duplicate experiments are summarized in table 3.

TABLE 3

Effectiveness of Flowers of Sulfur in Preventing Bunt Infection Under Varying Dosages of Spores in Experiments Conducted During 1921 at Davis

Per Cent of Bunt by Head Count

Treatment	Spore Dosage to Seed by Weight								
	1–30 Per Cent Bunt	1–250 Per Cent Bunt	1–500 Per Cent Bunt	1–750 Per Cent Bunt	1–1000 Per Cent Bunt	1–1500 Per Cent Bunt	1–2000 Per Cent Bunt	1–2500 Per Cent Bunt	1–3000 Per Cent Bunt
Check (Untreated)	61.5	47.3	51.3	35.4	31.6	26.5	21.6	21.3	10.9
Dipped Bluestone (1-5) 3″	.9	1.5	.6	.3	.3	0.0	0.0	0.0	0.0
Dipped bluestone (1-4) 8″; limed (1-8) 5″	.2	.1	0.0	0.0	.4	0.0	0.0	0.0	0.0
Dipped formaldehyde (1-40) 10″	2.4	3.0	.2	0.0	0.0	0.0	0.0	0.0	0.0
Sulfured 25 lbs. per 100 lbs. seed	32.6	7.2	5.2	6.9	4.0	2.5	.6	.1	.1
Sulfured 15 lbs. per 100 lbs. seed	43.5	5.6	9.3	6.2	4.2	4.8	2.2	.5	1.0
Sulfured 5 lbs. per 100 lbs. seed	37.0	18.1	19.0	10.5	9.5	5.2	4.0	3.8	.6
Sulfured 2 lbs. per 100 lbs. seed	49.9	28.0	20.3	14.2	14.4	7.4	7.1	.2	2.6
Sulfured 1 lb. per 100 lbs. seed	48.6	44.0	28.0	21.6	17.5	16.4	6.8	4.2	2.6
Sulfured ½ lb. per 100 lbs. seed	56.8	35.4	32.1	22.6	17.0	11.7	7.2	7.0	4.4
Sulfured ¼ lb. per 100 lbs. seed	65.4	51.9	34.6	18.4	20.4	16.5	7.9	5.2	8.7

The evidence of these experiments with sulfur indicate: (1) that flowers of sulfur sown with seed at rates varying from ¼ to 25 pounds of sulfur per 100 pounds of seed, reduces seed-borne infection but does not wholly prevent it; (2) as the quantity of sulfur is increased from ¼ pound to 25 pounds per 100 pounds of seed, the bunt attack is correspondingly reduced, but even the 25 pound rate does not entirely prevent infection; and (3) because of these limitations flowers of sulfur cannot be recommended as a practical remedy for bunt control.

TABLE 4

THE EFFECTIVENESS OF COPPER SULFATE POWDER IN PREVENTING BUNT INFECTION UNDER VARYING DOSAGES OF SPORES IN EXPERIMENTS CONDUCTED DURING 1921 AND 1922 AT DAVIS

Per Cent of Bunt by Head Count

Fungicide and Treatment	Germination Per Cent		Proportion of Bunt Spores by Weight								
	Lab.	Field	1–30 Per Cent Bunt	1–250 Per Cent Bunt	1–500 Per Cent Bunt	1–750 Per Cent Bunt	1–1000 Per Cent Bunt	1–1500 Per Cent Bunt	1–2000 Per Cent Bunt	1–2500 Per Cent Bunt	1–3000 Per Cent Bunt
Check (Untreated)	99.8	56.6	61.6	27.4	22.7	22.1	9.9	6.2	10.7	10.5	9.8
Solutions:											
Bluestone (1-5) 3″	34.7	38.1	.5	1.1	0.0	0.0	.7	0.0	0.0	0.0	0.0
Bluestone (1-4) 3″; limed (1-8) 5″	69.1	46.6	.6	1.2	.1	.5	0.0	0.0	0.0	.2	0.0
Formaldehyde (1-40) 10″	99.0	36.9	1.0	.6	.5	.6	0.0	.1	.2	.2	.5
Dusted:											
Bluestone powder—1 oz. per bu.	99.0	54.6	28.4	16.5	3.5	3.0	1.8	1.9	1.0	1.4	1.3
Bluestone-lime (2-1)—1½ oz. per bu.	100.0	54.3	43.9	17.6	7.5	5.7	4.7	1.5	.4	2.0	2.9
Bluestone powder—2 oz. per bu.	100.6	57.7	34.7	10.2	1.8	.6	0.0	.3	.4	0.0	1.2
Bluestone-lime (2-1)—3 oz. per bu.	99.3	53.4	40.7	12.6	3.0	1.8	3.7	0.0	1.2	1.1	1.1
Bluestone powder—3 oz. per bu.	99.6	54.4	23.6	6.4	1.3	.8	.3	2.5	1.1	0.0	.6
Bluestone-lime (2-1)—4½ oz. per bu.	99.5	54.2	31.6	3.1	7.2	.8	1.6	.5	2.4	1.1	.4
Bluestone powder—4 oz. per bu.	99.1	53.1	14.8	1.4	1.0	1.1	.5	0.0	.4	0.0	.1
Bluestone-lime (2-1)—6 oz. per bu.	99.5	54.0	28.7	8.7	2.7	4.7	.8	2.6	.8	0.0	.2
1922 CROP											
Check (Untreated)	86.8	50.8	36.8	41.4	45.5	39.5	25.7	31.9	22.		
Solutions:											
Bluestone (1-5) 3″	39.6	33.1	6.2	.8	.6	.5	0.0	0.0	.05		
Bluestone (1-4) 3″; limed (1-8) 5″	77.1	38.6	1.3	1.0	1.8	.1–	0.0	.4–	.1–		
Formaldehyde (1-40) 10″	88.0	34.9	0.0	.05	0.0	0.0	0.0	.1	0.0		
Dusted:											
Bluestone powder—1 oz. per bu.	92.2	53.4	42.6	22.9	13.1	8.9	5.1	7.5	2.6		
Bluestone-lime (2-1)—1½ oz. per bu.	93.5	49.8	38.6	33.1	16.8	20.0	19.3	12.5	12.8		
Bluestone powder—2 oz. per bu.	92.1	51.4	22.2	6.0	3.0	1.9	1.5	1.8	1.9		
Bluestone-lime (2-1)—3 oz. per bu.	92.0	56.0	41.0	23.1	21.4	7.9	10.7	9.6	6.8		
Bluestone powder—3 oz. per bu.	94.0	54.3	24.3	1.9	.9	3.3	2.0	1.0	1.2		
Bluestone-lime (2-1)—4½ oz. per bu.	92.0	55.6	37.2	26.5	22.3	10.9	7.6	4.3	7.7		
Bluestone powder—4 oz. per bu.	91.8	52.9	26.1	3.4	2.7	3.4	.4	2.5	0.0		
Bluestone-lime (2-1)—6 oz. per bu.	95.0	57.6	35.3	18.9	17.1	8.5	4.6	6.7	4.4		

CONTROL OF BUNT BY COPPER SULFATE POWDER

Bluestone and bluestone-lime solutions for seed treatment are preferred on the Pacific Coast to formaldehyde because seed injury is generally less, and, in addition, bluestone has a residual repressive effect against infection from bunt-infested soils. It is natural, therefore, that bluestone and bluestone-lime powder should be tested when dry treatments were considered.[22]

The results of two years' experiments with bluestone powder are reported in table 4.

Bluestone was prepared in various ways to test its effectiveness. First, powdered bluestone was shaken up with wheat at the rates of one, two, three, and four ounces per bushel of seed. As powdered bluestone is simply a mass of finely-divided crystals, the term powder is employed to differentiate it from copper carbonate dust, which is not crystalline, but amorphous.

As bluestone powder appeared to be caustic to seed germs,[22] lime dust was added in sufficient quantities to react with the bluestone—usually two parts of bluestone to one part of lime, as is the case with the liquid bluestone-lime method of seed treatment.

The increase in the amount of the bluestone powder from one to two ounces per bushel of seed in every case markedly increased its efficiency, but further increase to three and four ounces per bushel reduced the bunt attack little or not at all. It is evident, therefore, that two or three ounces per bushel are ample for the most effective control by this fungicidal powder.

Because seed injury from bluestone dust was anticipated, lime dust ($CaCO_3$) was added in sufficient quantities to react chemically with the bluestone. The results show in every case that the addition of lime decreased the effectiveness of the bluestone by increasing the bunt attack from two to four times. As sound seed does not show any injurious effect from the bluestone powder for any of the doses from one to four ounces per bushel, there appears to be no necessity for adding the lime.

One disadvantage of copper sulfate is its tendency to consolidate into masses, losing its powder form. This condition was thought to be due to the five molecules of water contained in bluestone ($CuSO_4.5H_2O$). Bluestone was heated to 103° C. and 206° C. respectively. Of the water of crystallization, only one molecule remained ($CuSO_4.H_2O$) at 103° C., and water-free anhydrous copper sulfate ($CuSO_4$) was secured at 206° C. After months of exposure to air, these anhydrous copper sulfate powders still remained powdered and apparently unaltered.

TABLE 5

USE OF ANHYDROUS COPPER SULFATE IN PREVENTING BUNT INFECTION UNDER A DOSAGE OF SPORES OF 1:750

Experiments Conducted During 1922 at Davis

Per Cent of Bunt by Head Count

Treatment	Germination Per Cent		Per Cent Bunt
	Lab.	Field	
Check (untreated)	99.8	68.0	28.6
Dipped bluestone (1-5) 3″	49.3	35.0	0.0
Dipped bluestone (1-4) 3″; limed (1-8) 5″	92.0	36.6	0.0
Dipped formaldehyde (1-40) 10″	99.6	48.2	0.0
Dusted bluestone*—2 oz.	98.0	51.0	6.6
Dusted bluestone*—4 oz.	100.0	54.3	1.2
Dusted bluestone dehydrated† at 103° C.—2 oz.	99.0	55.0	.1
Dusted bluestone dehydrated† at 103° C.—4 oz.	98.0	48.0	0.0
Dusted bluestone dehydrated† at 206° C.—2 oz.	100.0	53.3	0.0
Dusted bluestone dehydrated† at 206° C.—4 oz.	98.0	54.6	0.0

* Bluestone analyzed 98.27 per cent pure.

† Bluestone ($CuSO_4.5H_2O$) dehydrated at 103° C. loses 4 molecules of water, becoming $CuSO_4.H_2O$. When dehydrated at 206° C., the pure anhydrous form ($CuSO_4$) is secured.

The tests in table 5, made in duplicate, gave the following results for a bunt dosage of 1 to 750:

1. The checks with the standard solutions of bluestone, bluestone-lime, and formaldehyde were practically completely effective (over 99 per cent).

2. Other experiments not here reported showed that the addition of salt (NaCl) or lime ($CaCO_3$) to the bluestone powders did not materially help its efficiency, but, on the contrary, lime sometimes reduced bunt control. Germination was not affected.

3. Bluestone, dehydrated at temperatures of 103° C. and 206° C., caused no material change in the effectiveness of the bluestone powder.

4. The results obtained with anhydrous copper sulfate indicate no improvement in the control of bunt or the prevention of seed injury. However, the anhydrous form remains in a pulverized condition much more certainly than powdered bluestone.

COPPER SULFATE DUST AS A SUBSTITUTE FOR COPPER CARBONATE

As copper sulfate, or bluestone, is the basis for copper carbonate manufacture, there appears to be no reason why sufficient quantities of copper carbonate should not be manufactured.

Malachite, a copper carbonate mineral occurring in the United States, was investigated, but it was found to be available in very limited quantities, and rather impure. Experiments demonstrated that malachite as a bunt preventive was greatly inferior to well-prepared copper carbonate dust.

If, however, copper carbonate dust is not available in sufficient quantities, powdered bluestone may be used as a good substitute. Experiments conducted at Davis and in coöperation with farmers were successful, but the results were not as satisfactory as those in which copper carbonate dust was used. The greatest difficulty offered by bluestone lies in the fact that it is not easily reduced to a powder and in the further fact that it is difficult to maintain it in a loose powdered form sufficiently fine to adhere to seed.

MISCELLANEOUS CHEMICAL DUSTS

In addition to copper sulfate powder and copper carbonate dust, many other chemical powders and dusts were tested in an attempt to secure a common and relatively cheap fungicide. The list included malachite, paris green, barium carbonate, lead carbonate, ferrous sulfate, manganese dioxide, calcium carbonate, potassium sulfate, ammonium sulfate, sodium nitrate, superphosphate, sodium carbonate, sodium chloride, magnesium sulfate, and various combinations of lime and fungicides and of fertilizers. Some of them possess decided fungicidal properties, but all were far inferior to copper carbonate and copper sulfate in control of bunt. Seed injury occurred with paris green and superphosphate, but the addition of lime dust reduced or removed the injurious effects.

EFFECT OF COPPER CARBONATE DUST ON THE CONTROL OF BUNT

The accuracy of scientific experiments increases with the number of replications. The experiments with copper carbonate dust conducted for three years were repeated in duplicate in many series. During this period approximately 1,600,000 plants and 8,100,000 heads were individually examined, counted, and recorded.

TABLE 6

SUMMARY OF THE EFFECTIVENESS OF COPPER CARBONATE IN PREVENTING BUNT INFECTION UNDER VARYING DOSAGES OF SPORES IN EXPERIMENTS CONDUCTED DURING 1921 AND 1922 AT DAVIS

Per Cent of Bunt by Head Count

Fungicide and Treatment	Year	Germination Per Cent		Proportion of Bunt Spores by Weight								
		Lab	Field	1–30 Per Cent Bunt	1 250 Per Cent Bunt	1–500 Per Cent Bunt	1–750 Per Cent Bunt	1–1000 Per Cent Bunt	1–1500 Per Cent Bunt	1–2000 Per Cent Bunt	1–2500 Per Cent Bunt	1–3000 Per Cent Bunt
Check (Untreated)	1921	99.6	55.4	61.6	27.4	22.7	22.1	9.9	6.2	10.7	10.5	9.8
Check (Untreated)	1922	86.8	52.4	36.8	41.4	45.5	39.6	25.7	31.9	21.0	0.0	0.0
Solutions:												
Bluestone (1-5) 3″	1921	34.2	39.2	.5	1.1	0.0	0.0	.7	0.0	0.0	0.0	0.0
Bluestone (1-5) 3″	1922	44.1	33.2	6.3	.8	.6	.5	0.0	0.0	.1	—	—
Bluestone (1-4) 3″; limed (1-8) 5″	1921	72.3	47.1	.6	1.2	.1	.5	0.0	0.0	0.0	.2	0.0
Bluestone (1-4) 3″; limed (1-8) 5″	1922	77.3	38.8	1.3	1.	1.8	.1	0.0	.4	.1	—	—
Formaldehyde (1-40) 10″	1921	99.2	37.4	1.0	.6	.5	.6	0.0	.1	.2	.2	.5
Formaldehyde (1-40) 10″	1922	88.1	34.7	0.0	.1	0.0	0.0	0.0	.1	0.0	—	—
Dusts:												
Copper carbonate—1 oz. to bu.	1921	98.6	52.6	30.0	6.1	.2	.7	0.0	.2	0.0	.5	0.0
Copper carbonate—1 oz. to bu.	1922	91.7	53.5	36.6	22.7	5.3	2.2	.6	.1	.1	—	—
Copper carbonate—2 oz. to bu.	1921	99.6	54.5	17.7	.7	.5	0.0	0.0	0.0	0.0	0.0	0.0
Copper carbonate—2 oz. to bu.	1922	92.4	56.5	46.5	9.4	.3	1.2	0.0	0.0	0.0	—	—
Copper carbonate—3 oz. to bu.	1921	99.7	54.8	10.6	.7	.6	0.0	0.0	0.0	0.0	0.0	0.0
Copper carbonate—3 oz. to bu.	1922	92.4	54.8	34.1	1.1	.9	.4	0.0	.2	0.0	—	—
Copper carbonate—4 oz. to bu.	1921	99.8	52.6	3.4	.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Copper carbonate—4 oz. to bu.	1922	92.7	55.8	20.0	2.2	1.3	.1	0.0	0.0	0.0	—	—

The results obtained are reported (1) in table 6, covering experiments with copper carbonate dust upon various dosages of bunt spores; (2) in table 7, treating the subject of dilution of copper carbonate; and (3) table 8, relating to the effect of the chemical purity and physical fineness of copper carbonate upon bunt control.

In order to make these experiments as comprehensive as possible, and thus anticipate many questions likely to arise concerning the dust fungicides, nine rates of dosages of spores and four rates of chemical treatment were used. The copper carbonate treatments were checked against untreated seed and seed treated with the standard solutions, and compared with bluestone powder. The experiments with bluestone powder were carried on in connection with the copper carbonate dust because the former is always available and much cheaper than copper carbonate dust.

In order to render the data on copper carbonate more readily comparable, the statistical results of each year (1921 and 1922) have been summarized and placed adjacent.

The relative results of the two seasons do not vary in general and in no case is there a reversal in comparing each set of experiments. The results of the two years' tests are, therefore, discussed together.

With the decrease of the spore dosage, the per cent of bunt invariably decreased and directly affected the tests with the fungicidal dusts which followed.

The standard fungicidal solutions, bluestone, bluestone-lime, and formaldehyde, were practically fully effective, except for the heaviest dosage of blunt spores (1–30). So small was the difference between these three solutions that any one of them may be recommended so far as concerns the control of bunt from seed-borne spores. For reasons already advanced, the bluestone-lime method is preferred on the Pacific Coast when it comes to a choice of solutions.

When compared with the fungicidal solutions, copper carbonate is seen to be less effective for the heavier dosages (1–30 and 1–250), but is very effective for dosages of 1–750 and less.

Copper carbonate dust applied at four rates (1, 2, 3, and 4 ounces per bushel) when compared with the standard solutions, was found to be less effective up to a bunt spore load of 1–750, where it approximately completely controlled infection. At this point the seed is visibly darkened and is much smuttier than is advisable to sow under any circumstances (pls. 1 and 2). For the spore loads of 1–750 and less there was no gain in bunt control by increasing the dose of copper carbonate beyond two ounces per bushel. However, two ounces usually was found to be more effective than smaller quantities.

Copper carbonate in every instance was found to be more efficient than bluestone powder with or without lime. For dosages of 1–750 or less, copper carbonate was as efficient as the formaldehyde and bluestone treatments.

EFFECT OF THE DILUTION OF COPPER CARBONATE ON BUNT CONTROL

Copper carbonate dust when properly made contains more than 50 per cent of copper in the form of a compound of carbonate and hydrate of copper ($CuCO_3.Cu(OH)_2$) as basic copper carbonate. As this chemical is usually more than twice as rich in copper as bluestone ($CuSO_4.5H_2O$), containing 25.4 per cent copper, it has been advocated that a more dilute basic copper carbonate could be used. Copper carbonate dust of standard strength was therefore mixed with gypsum ($CaSO_4.2H_2O$) or with lime ($CaCO_3$) in a series of graded mixtures. The results on bunt control are reported in table 7.

The reduction of the spore load on the seed returned a corresponding reduction of bunt attack for untreated as well as for all treated seed.

Gypsum added to copper carbonate decreased its efficiency as a bunt preventive, in proportion to the amount added. Increased amounts of fungicidal dust from two to four ounces per bushel gave a corresponding decrease in the percentage of bunt, and with the decrease of the gypsum from 3 to 1 to pure copper carbonate, there was a corresponding decrease in the percentage of bunt.

The dilution of copper carbonate with lime dust gave almost identically the same results as dilution with gypsum, except that the control of bunt was somewhat less.

These experiments indicate that no beneficial results may be expected from diluting copper carbonate with non-fungicidal powders or dusts. However, it appears that copper carbonate may be diluted at the rate of 25 per cent without seriously reducing its effectiveness. If the dilution is increased to 50 per cent, the rate of treatment, to be effective, must be increased to four ounces per bushel, which means that copper carbonate is actually added at the rate of two ounces per bushel. Four ounces of dust is considerably more than will adhere to the seed. In these experiments the excess dust was sown with the seed. However, dusting machines are devised to take out all the dust except the quantity which adheres to the seed. If an excess of dust were left with the seed it would be blown away when broadcast seeders are used. A dilution of this dust would directly reduce the active fungicide. A concentrated, highly efficient dust fungicide is therefore deemed necessary.

TABLE 7

THE EFFECT OF DILUTING COPPER CARBONATE ON ITS USE IN PREVENTING BUNT INFECTION UNDER VARYING DOSAGES OF BUNT SPORES

Experiments Conducted During 1922 at Davis

Per Cent of Bunt by Head Count

Fungicide and Treatment	Germination per Cent		Spore Dosage to Seed by Weight		
	Lab.	Field	1–250 Per Cent Bunt	1–750 Per Cent Bunt	1–1500 Per Cent Bunt
Check (Untreated)	91.3	48.6	40.6	47.4	33.4
Solutions:					
Bluestone (1-5) 3″	22.0	25.2	1.1	.3	1.6
Bluestone (1-4) 3″; limed (1-8) 5″	60.3	35.5	2.7	1.7	.2
Formaldehyde (1-40) 10″	93.3	37.1	0.0	0.0	0.0
Dusts:					
1 part $CuCO_3$ to 3 parts $CaSO_4$—2 oz. to bu.	91.0	52.6	29.4	12.6	5.9
1 part $CuCO_3$ to 1 part $CaSO_4$—2 oz. to bu.	90.0	52.0	23.4	5.2	1.1
3 parts $CuCO_3$ to 1 part $CaSO_4$—2 oz. to bu.	94.0	53.6	11.8	.2	.5
1 part $CuCO_3$ to 0 part $CaSO_4$—2 oz. to bu.	95.0	54.3	4.9	1.1	.2
1 part $CuCO_3$ to 3 parts $CaSO_4$—4 oz. to bu.	98.0	51.6	17.4	3.9	1.1
1 part $CuCO_3$ to 1 part $CaSO_4$—4 oz. to bu.	94.0	52.3	2.3	.2	0.0
3 parts $CuCO_3$ to 1 part $CaSO_4$—4 oz. to bu.	95.0	50.6	1.6	0.0	0.0
1 part $CuCO_3$ to 0 part $CaSO_4$—4 oz. to bu.	97.0	57.3	.7	.8	0.0
1 part $CuCO_3$ to 3 parts $CaCO_3$—2 oz. to bu.	95.0	58.6	20.7	18.3	9.7
1 part $CuCO_3$ to 1 part $CaCO_3$—2 oz. to bu.	95.0	56.3	20.4	7.1	2.0
3 parts $CuCO_3$ to 1 part $CaCO_3$—2 oz. to bu.	95.0	49.6	5.1	1.1	.1
1 part $CuCO_3$ to 0 part $CaCO_3$—2 oz. to bu.	94.0	50.6	2.8	1.0	.1
1 part $CuCO_3$ to 3 parts $CaCO_3$—4 oz. to bu.	94.0	53.0	17.5	5.6	3.6
1 part $CuCO_3$ to 1 part $CaCO_3$—4 oz. to bu.	95.0	49.6	10.0	1.7	.9
3 parts $CuCO_3$ to 1 part $CaCO_3$—4 oz. to bu.	91.0	46.6	.7	.7	.1
1 part $CuCO_3$ to 0 part $CaCO_3$—4 oz. to bu.	90.0	56.3	1.6	.5	0.0

COMPARATIVE EFFECTIVENESS OF SOME COMMERCIAL SAMPLES OF COPPER CARBONATE

Copper carbonate dust from many sources has been sold on the Pacific Coast to be used for control of bunt. Due probably to differences in manufacture, no two commercial brands are identical in chemical and physical composition. In order to ascertain the effect of these differences in copper carbonate dust, a number of commercial brands were tested to determine their efficiency in control of bunt. The results are reported in table 8.

Copper carbonate No. 1 (table 8) appeared to be physically and chemically satisfactory and gave satisfactory bunt control for spore dosages of 1–750 and less. Number 2 gave results very similar to No. 1, except that it was more efficient for the 1–750 spore dosage. Sample No. 3 was not satisfactory, giving poor bunt control for all tests. This sample did not possess the light green fluffy appearance

TABLE 8

THE DIFFERENCE IN EFFECTIVENESS OF SOME COMMERCIAL SAMPLES OF COPPER CARBONATE IN PREVENTING BUNT INFECTION UNDER VARYING DOSAGES OF SPORES

Experiments Conducted During 1922 at Davis

Per Cent of Bunt by Head Count

Fungicide and Treatment	Germination per Cent		Spore Dosage to Seed by Weight		
	Lab.	Field	1–250 Per Cent Bunt	1–750 Per Cent Bunt	1–1500 Per Cent Bunt
Check (Untreated)	93.5	54.13	52.8	37.1	20.4
Solutions:					
Bluestone (1-5) 3″	24.5	29.8	.6	0.0	.4
Bluestone (1-4) 3″; limed (1-8) 5″	56.0	44.0	1.3	.2	.3
Formaldehyde (1-40) 10″	81.0	35.6	.2	.1	0.0
Chlorophol II, 2-3 gr. litre	93.5	60.3	.1	0.0	0.0
Dnsts:					
$CuCO_3$—No. 1—2 oz. to bu.	91.0	58.9	5.5	.4	.3
$CuCO_3$—No. 1—4 oz. to bu.	93.0	55.2	4.3	1.6	0.0
$CuCO_3$—No. 2—2 oz. to bu.	94.0	57.3	8.9	.1	1.1
$CuCO_3$—No. 2—4 oz. per bu.	94.0	59.5	3.7	0.0	0.0
$CuCO_3$—No. 3—2 oz. per bu.	93.0	55.1	23.2	9.9	2.4
$CuCO_3$—No. 3—4 oz. per bu.	95.0	56.6	21.1	4.4	3.6
$CuCO_3$—No. 4—2 oz. per bu.	91.0	59.8	16.1	5.1	2.5
$CuCO_3$—No. 4—4 oz. per bu.	93.0	58.1	9.9	.4	.2
Chlorophol—No. 2—2 oz. per bu.	93.0	60.4	19.4	2.4	.4
Chlorophol—No. 2—4 oz. per bu.	91.0	59.1	3.3	1.0	1.6

of the satisfactory samples, but was denser and coarser and of a darker color. Sample No. 4 gave satisfactory control when applied at the rate of 4 ounces per bushel, but was unsatisfactory at the rate of 2 ounces. It is a commercial compound with a copper carbonate base and contains about half as much copper as pure copper carbonate. Since it was necessary to use 4 ounces per bushel, approximately the same quantity of copper was required as if 2 ounces of copper carbonate had been used.

Chlorophol (a patented chloro-phenol-mercuric compound),[27, 28] gave excellent control as a liquid. The results indicate that organic mercuric compounds offer possibilities as dust fungicides.

EFFECT OF FUNGICIDAL DUSTS UPON SEED GERMINATION

Fungicidal solutions employed to control infection from seed-borne bunt spores have been shown to cause severe injury to seed germination,[6, 16, 21] and great reduction in germination. When such seed is sown in the field, poor stands result unless overcome by a very heavy increase in the rate of seeding. Farmers have reported sowing from 120 to 200 pounds of wheat per acre in an effort to overcome seed losses, a very considerable portion being due to seed treatment. As will be shown later, the soil itself takes a heavy toll of seed.

When seed is dusted with copper carbonate it may be left indefinitely without fear of seed injury so far as the fungicide is concerned.[14] It even appears to have a somewhat repellent effect upon grain weevils. As copper carbonate dust does not attract moisture from the air, no reaction occurs until it comes in contact with the soil moisture. When there is sufficient soil moisture to start germination, moisture conditions are satisfactory for causing the copper carbonate to go into solution and become active.

All treated seed sown in the plots was tested in the seed-testing laboratory of the United States Department of Agriculture.* At harvest time all plants were pulled and counted, and were then classified as bunted or clean. In this manner, a practical check on the survival of the seed sown in the soil was recorded. The germination of seed under laboratory and field conditions are given in table 9.

It is evident at once that the chemical solutions cause a great deal of injury to germination. On an average, only 31.4 per cent of the bluestoned seed survives in the soil, and but slightly more (39.6 per cent) under germination in the laboratory. The bluestone-lime dips show very favorable germination in the laboratory (73.6 per cent), but little more than half (53.8 per cent) as much when germinated in the soil. The lime bath following the bluestone solution saves 26 per cent of the seed when compared with the bluestone alone. The formaldehyde under the favorable soil and moisture conditions at Davis gave as high germination in the soil as bluestone-lime.

The chemical dusts, as a whole, cause practically no injury when compared with the untreated checks. Some depression appeared

when common salt (NaCl) was added to the bluestone powder. To offset the depression caused by the salt, lime was added, with the result that the germination in soil was considerably superior to the untreated check plots. The addition of the lime, however, reduced the control of bunt. Copper carbonate dust in a large number of experiments gave somewhat better germination in the soil than the untreated seed.

TABLE 9

INFLUENCE OF SEED TREATMENT ON THE PER CENT OF GERMINATION OF SEED TESTED IN THE LABORATORY AT BERKELEY AND SEED PLANTED IN THE FIELD AT DAVIS DURING 1921 AND 1922

Fungicide and Treatment	No. of tests	Germination Per Cent	
		*Lab.	Field
Check (Untreated)	112	95.1	53.8
Solutions:			
Bluestone (1-5) 3″	112	38.1	31.4
Bluestone (1-4) 3″; limed (1-8) 5″	112	73.6	39.6
Formaldehyde (1-40) 10″	112	93.6	41.5
Dusts:			
Copper carbonate—4 oz. to bu.	32	96.2	54.2
Bluestone—4 oz. to bu.	32	95.4	53.0
Bluestone+lime (2-1)—6 oz. to bu.	32	97.2	53.3
Bluestone dehydrated at 103° C—4 oz. to bu.†	2	98.0	48.0
Bluestone dehydrated at 206° C—4 oz. to bu.	2	98.0	54.6
1 part $CuCO_3$ to 3 parts gypsum—4 oz. to bu.	6	98.0	51.6
1 part $CuCO_3$ to 1 part gypsum—4 oz. to bu.	6	94.0	52.3
3 parts $CuCO_3$ to 1 part gypsum—4 oz. to bu.	6	95.0	50.6
Sulfur: 25 lbs. per 100 lbs. seed	18	99.0	53.2

* We are indebted to Miss Etta Gilbert and Miss Grace Cole of the California Branch of the Seed Laboratory for germination tests.

† Bluestone ($CuSO_4.5H_2O$) dehydrated at 103° C. loses 4 molecules of water, becoming $CuSO_4.H_2O$. When dehydrated at 206° C. the pure anhydrous form, $CuSO_4$, is secured.

The effect of the soil (Yolo silt loam) at Davis on seed germination was to reduce the natural air germination of seed wheat from 95.1 per cent to 53.8 per cent. Soils of a sandier texture would, of course, give better germination than those at Davis, but, on the other hand, harsher, heavier, poorly drained soils would give poorer germination and stands of grain. Undoubtedly the rate of seeding and consequent stand of grain is greatly influenced by the effect of soil texture on treated as well as untreated seed.

PLATE 1

White Federation wheat. Dorsal side, × 30 diameters. Bunted at the rate of 1 part bunt spores to 3000 parts of seed. Approximately 1600 bunt spores per kernel.[15] As these are so few they are not visible to the naked eye and the seed passes as bunt free.

PLATE 2

White Federation wheat. Ventral side, × 30 diameters. Bunted at the rate of 1 part of bunt spores to 3000 parts of seed. Approximately 1600 bunt spores per kernel.[15] As these are so few they are not visible to the naked eye and the seed pass as bunt free.

PLATE 3

Little Club. Bunt free. Dorsal and ventral sides. × 30 diameters. The surface of seed wheat appears smooth to the naked eye, but the surface is here seen to be quite rough and capable of holding spores and copper carbonate dust readily.

STIMULATION OF WHEAT SEEDLINGS BY COPPER CARBONATE DUST

Although the experiments conducted during 1920[22, 23] were very limited in scope, they clearly indicated that no injury to germination resulted from treating seed wheat with copper carbonate. Germination tests conducted in the laboratory at Berkeley and in the field at Davis in connection with a large number of experiments during

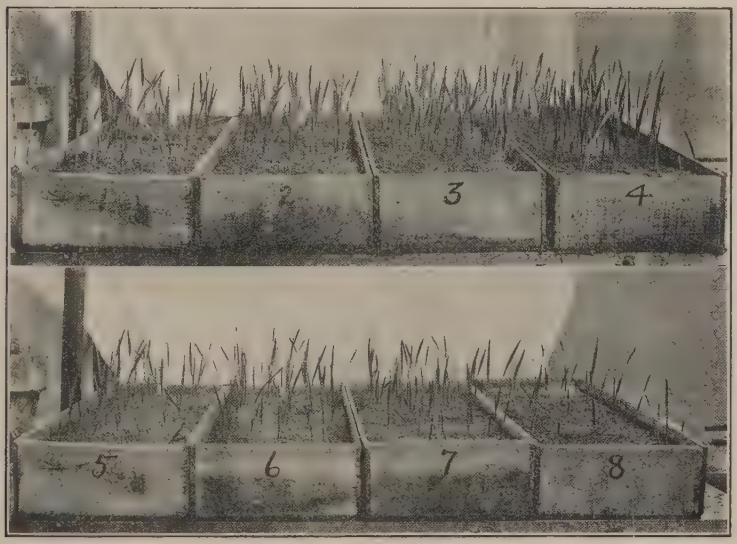


Fig. 4.—Stimulation of wheat seedlings by copper carbonate dust.

a. Effect of fungicidal dusts on wheat seedlings. Left to right: No. 1, untreated seed; No. 2, bluestone dust applied at the rate of 4 ounces per bushel; No. 3, bluestone-lime dust mixed (2 to 1) and applied 6 ounces per bushel; No. 4, copper carbonate dust, 4 ounces per bushel.

b. Effect of fungicidal solutions upon wheat seedlings: left to right: No. 5, untreated seed; No. 6, bluestone solution (1 lb. to 5 gals.), soaked 3 minutes; No. 7, bluestone dip (1 lb. to 4 gals.), soaked 5 minutes, followed by lime bath (1 lb. to 8 gals.), applied 5 minutes; No. 8, formaldehyde solution (1 pt. to 40 gals.), submerged 10 minutes.

1921 and 1922, show that seed treated with copper carbonate dust is equal to untreated seed and is superior to seed treated by the standard solutions. Seed treated with copper carbonate sprouted a few days earlier and grew more vigorously throughout the season than the others.

Preliminary greenhouse experiments on wheat seedlings likewise indicate a decided stimulation following the use of copper carbonate.

Numerous demonstrations on the use of copper carbonate treatments have been conducted throughout the state under the supervision of the farm advisors. All agree that no seed injury is evident where copper carbonate is used. Many report that seedlings from copper-carbonate treated seed emerge earlier and grow more vigorously than seedlings from untreated seed or from seed treated with the usual solutions. Others note no stimulation whatever.

Reports from Washington[31] and Oregon[1] corroborate the observations made in California on the absence of seed injury and apparent stimulation of seedlings by copper carbonate.

STANDARDS OF CHEMICAL PURITY AND PHYSICAL FINENESS FOR COPPER CARBONATE DUST

Commercial copper carbonate contains to a small extent various foreign ingredients due to the process of manufacture. The basis of manufacture consists of bluestone ($CuSO_4.5H_2O$), which usually contains a small quantity of iron, a survival in the manufacture of sulfuric acid from iron pyrites. Sodium carbonate is added to the copper sulfate solution, with the result that the copper carbonate is precipitated and the soluble sodium sulfate, a product of the reaction, is washed out, thus removing the sulfuric acid ion. When dried, the resultant powder is amorphous, entirely without crystals if pure, and greenish in color. Blue color indicates the presence of copper sulfate and an incomplete product. The chemical formula appears to be as follows: $CuCO_3.Cu(OH)_2$. The proportions of $CuCO_3$ and $Cu(OH)_2$ vary widely, according to the care exercised in its manufacture. If too much heat is applied, carbon dioxide, added as sodium carbonate (Na_2CO_3), is driven off as gas. This increases the proportion of copper hydrate at the expense of the copper carbonate. Still further heating decomposes the rather unstable copper hydrate, leaving as a result inert, dark brown copper oxide. The commercial product consists of a basic copper carbonate, amorphous in texture, very stable under ordinary conditions, and not subject to deliquescence or crystallization. Copper carbonate is listed as insoluble in pure water, but it is slowly soluble in dilute acids, such as carbonic, dicarbonic, and undoubtedly many organic acids which normally occur in the soil. It is this quality of slow but certain solubility which enables this fungicide to exert for a considerable period a continuous repressive and lethal effect upon germinating bunt spores whether held upon the seed or occurring in the soil in the immediate vicinity of the seed.

As copper carbonate is normally manufactured for use in the arts, and not for fungicidal purposes, no special efforts were made to standardize its chemical and physical composition. At the inception of the experiments with copper carbonate dust, variations in its chemical and physical composition were noted. These variations were reflected in its efficiency as a preventive of bunt. Farmers complained of this condition and requested information concerning standards of

TABLE 10

Chemical Analysis of the Four Lots of Copper Carbonate, the Effectiveness of which is Reported in Table 8

Sample Number	1	2	3	4
Chemical Analysis in Per Cent				
Copper (Cu)	54.4	53.8	46.6	21.3
Carbon dioxide (CO_2)	19.4	18.3	15.9	8.6
Hydroxylion (OH)	14.0	14.4	16.3	7.2
Sulfuric anhydride (SO_3)	0	0	0	27.5
Iron (Fe)	tr.	0	0	.73
Calcium oxide (CaO)	v.sm.	v.sm.	some	24.3
Loss on ignition	29.4	30.3	30.2	21.9
Insoluble residue	small	small	small	0
Recombined as Salts				
Copper carbonate ($CuCO_3$)	54.6	51.5	44.8	24.3
Copper hydrate Cu $(OH)_2$	40.3	41.5	46.9	20.7
Copper sulfate ($CuSO_4$)	0	0	0	0
Basic copper carbonate $CuCO_3.Cu(OH)_2$	94.9	93.0	92.0	45.1
Density—Physical Fineness				
Pounds per cubic foot	28.12	43.75	76.25	36.25

[1] Analyses by Prof. M. E. Jaffa, Harold Goss and Thos. B. Swift.

* We are indebted to Prof. M. E. Jaffa and Mr. Harold Goss of the University of California, and Mr. Thos. B. Swift, for the analyses in table 10.

purity and efficiency. Analyses were made of various samples of copper carbonate dust sold to the farmers. Representative samples were tested for bunt control and reported in table 8. Chemical analyses of these samples are given in table 10.*

In regard to bunt control, one of the samples (No. 3, table 8) gave poor results. This sample contained but slightly less copper (No. 3, table 10) than those samples which gave good results. On examination it was found to be gritty and to contain crystals blue in color. Zinc oxide was present in considerable quantities, together with quan-

tities of soluble chlorides and other salts. Sample No. 4 contained sulfates in large quantities, apparently in the form of calcium sulfate. The calcium sulfate may have resulted from the peculiar processes of manufacture, or from addition of calcium sulfate as a dilutant. As has been shown in numerous experiments (table 7), the addition of various quantities of lime ($CaCO_3$) or gypsum ($CaSO_4.2H_2O$) caused a corresponding reduction in efficiency of bunt control. The addition of dilutants appears to be a practice of doubtful value. The results indicate that the farmer should use the best and purest copper carbonate dust obtainable, even at an increase in price over less efficient and less costly copper carbonate compounds.

It is difficult to increase copper carbonate in basic copper carbonate beyond 55 per cent. By comparing the per cent of this copper carbonate with copper in satisfactory samples, it is seen that copper and copper carbonate are approximately equal. Wide departures from this proportion should be carefully scrutinized.

The first three samples of copper carbonate dust employed in the experiments in table 8 contained sufficient quantities of copper to insure good results, judging by comparative analyses (table 10). However, No. 3 gave poor bunt control. On examination, its physical condition was found to be poor—that is, the particles were coarse, and the fine, silky feeling common to the best samples was lacking. This led to the examination of fineness of the particles of copper carbonate dust in order to arrive at a reasonable standard for fineness. The results of the physical analyses of four samples tested in table 8 are reported in table 10.

In determining the physical condition of copper carbonate dusts, two tests were found necessary: (1) the determination of the density (weight of a given volume) of the dust, and (2) the fineness of the dust particles. The density was determined by shaking down a given weight in a measured cylinder, and the fineness by passing the material through a 200-mesh sieve while in aqueous suspension. By these tests those samples which gave the best control of bunt were found to average about 31 pounds per cubic foot. Over 99 per cent of this material passed through the 200-mesh sieve. On the other hand, it should be noted that the copper carbonate (sample No. 3, table 8) which gave the poorest bunt control returned the highest density, 78.84 pounds per cubic foot, with reduced quantities, 91.85 per cent passing through the 200-mesh sieve (sample No. 3, table 10). As the amount of copper (47.3 per cent) was not too low for fair results, the lack of bunt control may be charged to the excessive density and coarseness of the material, i.e., poor physical condition.

SUGGESTED QUALITIES FOR A STANDARD COPPER CARBONATE

With a method as new as the copper carbonate dust treatment, it is difficult to fix a standard for chemical and physical qualities. The experiments conducted at Davis, and the reports from farmers over the Pacific Coast States, indicate the necessity for an approximate

TABLE 11

Comparison of the Per Cent of Copper in a Number of Commercial Lots of Copper Carbonate

Sample No.	Copper (Cu) Per Cent	Copper carbonate ($CuCO_3$) Per Cent	Copper hydrate ($Cu(OH)_2$) Per Cent	Copper sulfate ($CuSO_4$) Per Cent	Calcium oxide (CaO) Per Cent	Iron (Fe) Per Cent	Basic copper carbonate $CuCO_3.Cu(OH)_2$ Per Cent	Density lbs. per cubic ft.
1	54.37	54.14	39.93		.30	.48	94.07	30.90
2	53.12	51.76	46.81			.76	98.57	
3	55.80	54.97	43.46			.57	98.43	
4	50.80	3.81	55.81	39.81	.75	2.30	59.62	
5	47.32	60.38	23.59	5.90 [3]	.81	.47	83.97	78.84
6	12.85	29.73	23.54	35.70	36.41 [1]	.35	53.27	34.71
7	21.90	25.01	19.74	15.55	24.33	.54	44.75	31.88
8	55.80	65.41	34.01			.65	99.42	
9	53.24	8.87	48.78	42.57	.56	.66	57.65	55.82
10	51.88					1.19	93.70	
11	55.58	65.41	33.69			.65	99.10	
12	54.11	55.75	39.05		tr.	.56	94.80	
13	54.40	54.61	40.38		v. small	tr.	94.99	28.12
14	53.80	51.51	41.50		v. small		92.01	43.75
15	53.30	51.48	40.55		small		92.03	35.00
16	46.60	48.80	46.95		some		95.75	76.25
17	50.60	52.61	40.47		small		93.08	62.50
18	53.80	52.35	38.92		v.v.small	tr.	91.27	51.25
19	21.30	24.38	20.75		v.lge[2]	.73	45.13	36.25
20	52.90	53.68	39.20		large		92.88	66.35

Copper average in 12 uniform samples ..... 55.30 per cent
Copper carbonate average for the same 12 samples ..... 53.96 per cent
Copper hydrate average for the 12 samples ..... 39.83 per cent

[1] The calcium oxide combined as calcium carbonate in this mixture.
[2] The calcium oxide is here combined as barium sulfate in large proportions.
[3] This material is zinc oxide which may be combined as zinc sulfate.

standard. The results of experiments reported in tables 10 and 11 indicate that the following qualifications for copper carbonate dust may be required without materially adding to the cost of manufacture, but which will at the same time provide the farmer with an effective copper carbonate dust:

1. Copper carbonate dust should consist of 51 to 54 per cent of $CuCO_3$ and 39 to 42 per cent of $Cu(OH)_2$. The former may range from 50 to 60 per cent, and the latter from 35 to 48 per cent of the dust, but best results may be anticipated from the more regular composition. The combination of $CuCO_3.Cu(OH)_2$ should comprise 94

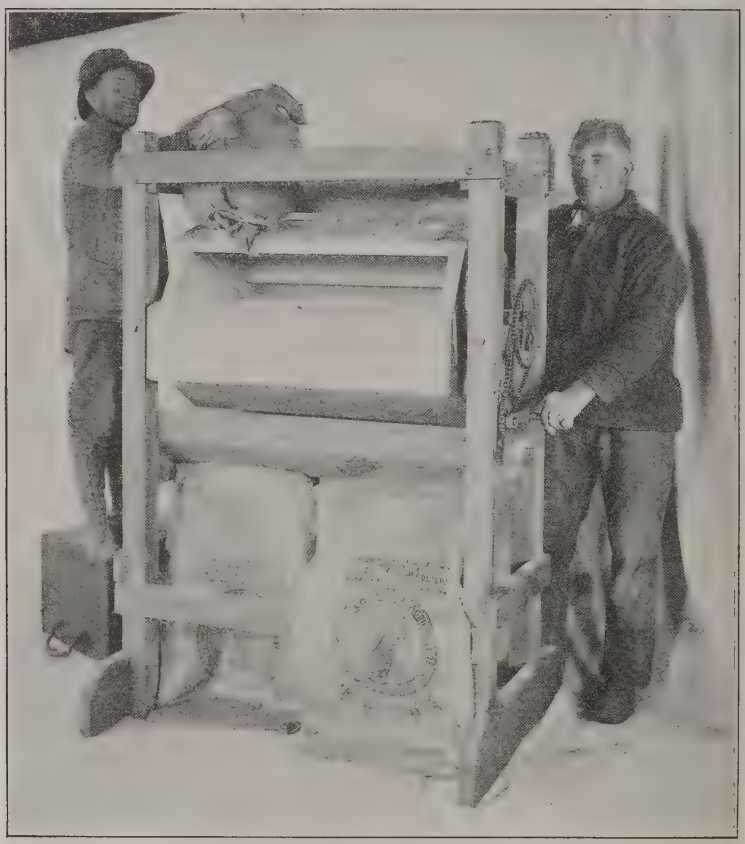


Fig. 5.—California Dusting Machine, front view.

per cent of the fungicide, but may vary from 92 to 98 per cent for good material.

2. Copper should not be less than 50 per cent, may average 53 per cent to advantage, and may rise to 55 per cent of the dust. It should be found solely in the carbonate and hydrate forms and not as sulfates or oxide.

3. Inert or foreign matter may include iron, silica, and slight amounts of sodium sulfate and non-fungicidal material not to exceed 6 or 7 per cent.

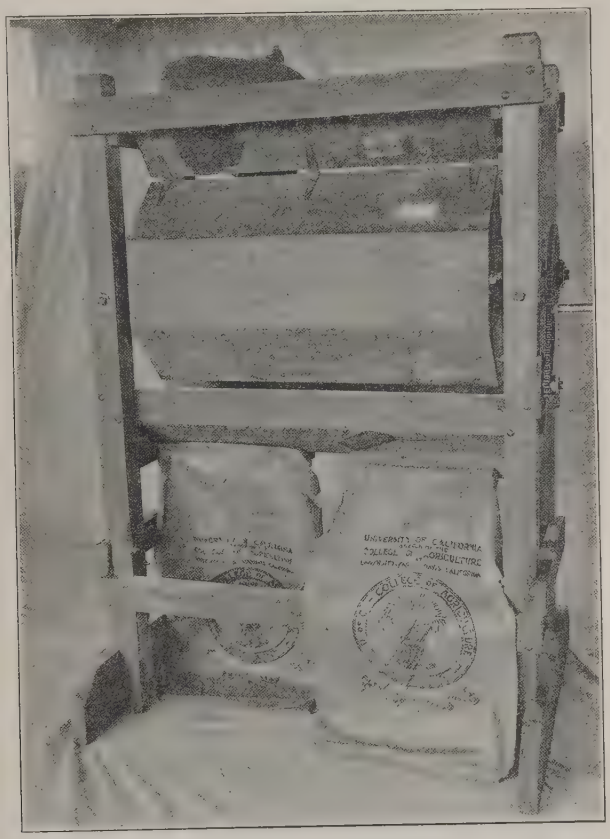


Fig. 6.—California Dusting Machine, rear view.

4. Copper carbonate dust should not be of greater density than 32 pounds per cubic foot when shaken down in a graduated tube. Lower density is desirable.

5. Not less than 99 per cent of the copper carbonate dust in aqueous suspension should pass through a 200-mesh sieve.

MACHINES FOR APPLYING COPPER CARBONATE DUST

In Australia copper carbonate dust has given good results,[7, 8, 9, 10] but has not been used extensively except by small farmers. This, it is stated, is due to the lack of proper machinery for applying the dust thoroughly and economically to large quantities of seed.

Fig. 7.—California dusting machine. Side view showing sprockets and opening to the wooden container.

The barrel churn has been used where small lots are treated. A modification of the barrel churn, or concrete mixer, has been put out by the Division of Agronomy of the University of California Experiment Station. This machine is a modification of the Washing-

ton State College smut treating machine.[14] It is constructed almost entirely of wood and can be made on the farm with common tools if the wheels and sprockets for tumbling the container be provided. It has a capacity of one sack of seed wheat every five minutes. Two minutes are required to mix the seed and dust and three minutes for filling, emptying and charging with the dust. Blueprints of this machine may be secured from the Agricultural Extension Service Division, at Berkeley.

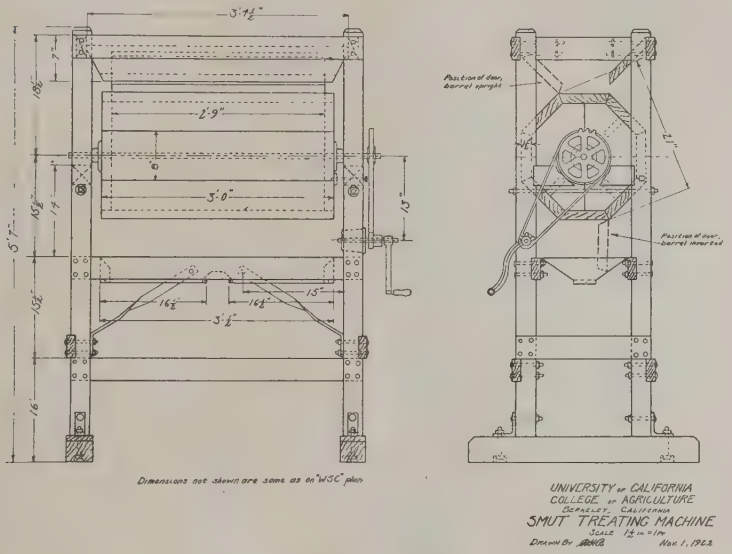

Position of door, barrel upright
Position of door, barrel inverted
Dimensions not shown are same as on "WSC" plan
UNIVERSITY OF CALIFORNIA
COLLEGE OF AGRICULTURE
BERKELEY, CALIFORNIA
SMUT TREATING MACHINE
SCALE 1½ in. = 1 ft.
DRAWN BY
NOV. 1, 1912

Fig. 8.—California dusting machine. Diagram.

Machines patterned after the automatic screw elevator type of machine, such as used in whitening smutty or dark colored barley at the large exporting warehouses, are in use. This type of machine automatically receives the seed and dust, mixing them in the passage of the seed through the enclosed screw elevator, but the loss of dust into the air is detrimental to workers.

A very successful automatic duster is in use at Westhaven, Fresno County. The principle on which the process depends consists in gravity action operating as the seed is received from the cleaner and grader. Copper carbonate dust is automatically blown into the top of the machine and is sucked down through it by means of a fan driven by a ¾ h.p. electric motor. Baffle boards tumble the descending grain, mixing it thoroughly with the fungicidal dust. This

machine is simpler than the others and far less costly in construction. It is air-tight, being made of tongue and groove lumber. No dust escapes except at the sack filler, and here in such small quantities that the operator does not require a mask. In size it is 116 inches high, and 36 inches by 19 inches for the cross section. It is designed

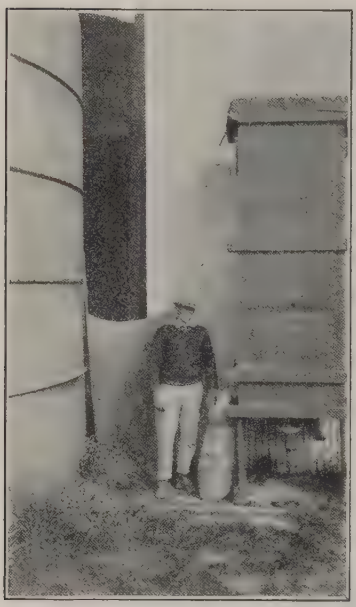
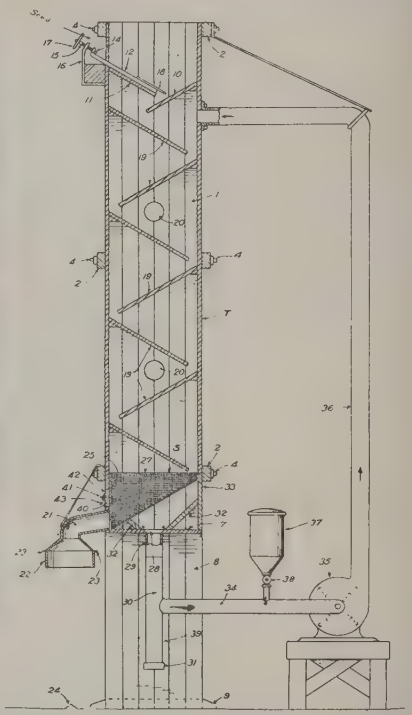


Fig. 9.—Universal duster. Cleaned and graded seed received at the upper end. The dust is mixed by gravity and a forced blast. Capacity: 150 to 300 bushels per hour. No dust mask was required when the machine was well fitted and thoroughly varnished to fill all cracks.

UNIVERSAL
SEED CONDITIONER AND DUSTER APPARATUS



Frederick Steigmeyer, Inventor. Patent applied for.

Fig. 10.—Diagram of the Universal dusting machine.

to thoroughly dust 150 bushels per hour, but can be adjusted to double this capacity. When used in connection with seed cleaning machinery, no extra help is required, as the grain may either be sacked or elevated to a bin and stored awaiting seeding time. This type of dusting machine should be very serviceable in connection with grain elevators or warehouses where seed is cleaned, graded and sold. A centralized treating plant equipped with such a machine might

well be operated by the farm bureau or similar organizations. With little or no additional expense beyond the cost of the copper carbonate dust, seed wheat may be treated ready for seeding at time of cleaning. Automatic seed treatment by this method should cheapen this process much below the cost to the farmer under ordinary farm operations. Loss of time may be eliminated at the seeding season by treating the seed in advance since no seed injury results from storing seed treated with copper carbonate dust.[14]

It is hoped that this dusting of seed wheat with copper carbonate dust by automatically operated machinery will lead to universal seed treatment. If such practices could be put continuously into effect, there is evidence that bunt might be reduced to a small minimum, and in many areas entirely eliminated.

EFFECT OF COPPER CARBONATE DUST UPON OPERATORS

Many complaints have been received concerning the nauseating effect of copper carbonate dust when inhaled. In some instances farmers have reverted to the liquid treatment of seed wheat, even though the copper carbonate method is preferable, because of this irritating quality of the dust. In the process of manufacture it causes the same trouble, but the use of masks permits the operators to work indefinitely in its presence without injury. The mask found to give the best service at these plants (fig. 11) depends in one form upon a wet sponge for its effectiveness and in the other on a dry filter paper. Both are light and permit easy breathing and ordinary conversation while working. The cost retail is $1.75 and $2.00 each.

If the worker cannot secure a mask, it is possible to avoid considerable dust irritation by tying a wet bandana handkerchief or similar cloth over the nose and mouth.

Although no feeding tests have been made, it does not seem advisable to feed wheat which has been treated, because copper carbonate is poisonous.

DEMONSTRATIONS WITH COPPER CARBONATE DUST ON FARMS

Many demonstrations were made on California grain farms in 1921.[24] In 1922, coöperative demonstrations were made in eighteen counties, under the direction of farm advisors or county agents. Almost 15,000 acres were sown with copper carbonate dusted seed. Similar demonstrations were held in Washington[31] and Oregon.[1] The results secured for the 1922 harvest in these three Pacific Coast states are recorded in table 12.

The control of bunt by copper carbonate dust, as shown in the records of table 12, indicate that: in California it is almost completely effective; in Washington, more so than other fungicides; and in Oregon, as efficient as bluestone. Since bluestone, bluestone-lime, and

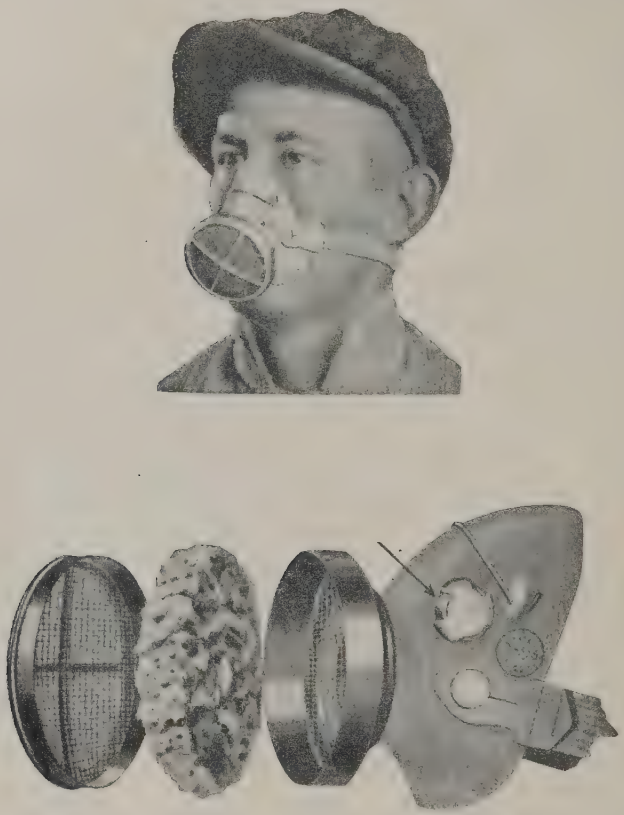


Fig. 11.—An effective device which successfully prevents inhalation of copper carbonate dust.

formaldehyde are recognized preventives of infection from seed-borne spores, the lack of complete control denotes either that the seed was too heavily smutted or that the attack came from bunt-infested soil and was therefore beyond the reach of fungicides applied to the seed. The details of these investigations are reported in the discussion which follows.

A critical point in bunt control lies in the thorough application of the copper carbonte dust to the seed. Lack of intimate mixing has been reported as the cause for lack of better control. So tenacious are the small amorphous particles of copper carbonate that with a low power microscope they are seen to adhere to every portion of the seed coat in a manner not unlike that of the bunt spores themselves. Even when dusted seed wheat is sown by the broadcast seeder, the particles of copper carbonate dust still adhere to all parts. In the

TABLE 12

Summary of Bunt Control Tests with Copper Carbonate in the Pacific Coast States for the 1922 Harvest

	Washington [1]		Oregon [1]		California	
	Number trials	Bunt per cent	Number trials	Bunt per cent	Number trials	Bunt per cent
Counties reporting	9		6		18	
Farms reported	75		31		40	
Bunt, untreated seed	8	93.7	0	0.0	31	6.0
Bunt, bluestoned seed	28	10.7	17	2.4	16	3.0
Bunt, bluestone-limed seed	10	9.0	1	0.0	7	2.0
Bunt, formaldehyded seed	33	6.9	14	0.8	8	2.0
Bunt, formaldehyde-lime seed	3	6.6	0	0.0	0	0.0
Bunt, copper carbonate	75	5.4	31	2.3	35	.6

[1] These tests were conducted under the supervision of county agents and reported for Oregon by Prof. H. P. Barss,[1] Plant Pathologist, Oregon Agricultural Experiment Station, and for Washington by Prof. George L. Zundel,[28] Extension Plant Pathologist of the Washington State College.

drill, friction removes but little of the dust, and in addition any excess dust over that held by the seed coat is sown with the seed, adding to its effectiveness.

Farmers have complained of poor bunt control by copper carbonate compounds lacking in physical fineness and chemical purity similar to the qualifications set forth in table 10.

The absence of germ injury to seed wheat treated with copper carbonate has been conclusively demonstrated by hundreds of carefully controlled tests. Everywhere farmers have observed the same results. While complaints of seed injury caused by formaldehyde and bluestone treatments have been frequent, none have been received against copper carbonate. According to the reports from county agents on the Pacific Coast, the percentage of plants per acre for copper carbonate-treated seed, compared with other seed treatments,

is greater by 30 to 50 per cent, but in many cases the range is much greater. Occasionally some farmer complains of too thick a stand from copper carbonate treated seed. Certainly a better stand is secured from copper carbonate-treated seed than from seed treated with either bluestone or formaldehyde-treated seed sown at the same rate.

Many farmers report that the copper carbonate-dusted seed sprouted several days ahead of seed otherwise treated, or untreated. When these fields have been contrasted, the differences are quite evident. Stimulation of seedlings by copper carbonate frequently pushes them out of the soil before crusts form to delay emergence. Thicker stands have caused weed suppression and increased yields. The majority of the farmers who used copper carbonate dust in 1922 report better yields from fields sown with dusted seed than from fields sown with seed treated by liquid fungicides, or from fields sown with untreated seed.

Farm tests are more or less variable, owing to variations in application of the fungicide and the spore load. Soil infestation by bunt spores also disturbs bunt control. The application of copper carbonate dust will undoubtedly be improved when serviceable dusting machinery is available.

It is not to be expected that this dust fungicide will give better control of seed-borne bunt than the standard solutions, but that it will equal them in this respect except when the seed is blackened with bunt spores. Though the control of bunt by copper carbonate is no better than with the standard fungicide, the increase in the number of plants and heads per acre has resulted in better yields. These outstanding advantages following the use of copper carbonate should result in the general adoption of this dust fungicide as a bunt preventive.

SOURCES OF COPPER CARBONATE

Difficulty in securing copper carbonate in sufficient quantities has been encountered. If the use of this fungicide is to become general, then sufficiently large supplies should be available to meet all needs. Three sources of supply exist: (1) importations from Germany; (2) manufacturers on the Atlantic seaboard; and (3) local manufacturers. The copper carbonate from abroad and from eastern sources is manufactured for the metallic arts and not for use as a dust fungicide, and it may be at times too coarse for entirely successful control of infection from seed borne spores. No doubt this difficulty can be

remedied if special orders are placed for copper carbonate of a specified physical quality and chemical purity. In the San Francisco bay region three or four chemical concerns are now manufacturing copper carbonate dust for use as a fungicide. By consultation with these firms the specifications for the qualities of effective copper carbonate have become understood, and improvement in the quality of the fungicide put out has followed. Owing to the comparative newness of the dust method for bunt control, manufacturers are reluctant to create large stocks which may remain unsold. Many farmers complain, however, that they have had to treat their seed by the old methods for lack of supplies of copper carbonate. In 1920, only a few ounces were used; in 1921, about 12,000 to 15,000 acres were sown with treated seed; but in 1922, estimates place the acreage at more than 250,000.

SUMMARY

1. Many fungicidal solutions, though destructive to bunt spores on the seed, injure and destroy seed germs. Distorted plants, delayed growth, and poor stands frequently occur. Bluestone represses root growth, and formaldehyde represses plumule development.

2. All poor stands are not caused by seed treatment, for soil and weather conditions prevent a large portion of the seed from developing into seedlings. A reduction of germination to almost 50 per cent occurs commonly on the University Farm at Davis, California (table 9).

3. Seed treated by fungicidal solutions showed reductions in germination in the soil when compared with laboratory germinations in 112 tests as follows:

Formaldehyde	96.3 to 41.5 per cent
Bluestone	38.1 to 31.4 per cent
Bluestone-lime	73.6 to 39.6 per cent

4. Flowers of sulfur reduced bunt to about one-tenth of the infection which occurred in similar unsulfured seed even where the dosage of smut spore was light. Sulfur is not a dependable bunt fungicide.

5. The amount of bunt in a crop depends in large part upon the quantity of bunt spores borne by the kernel. The per cent of bunt decreases with the spore dosage.

6. Bluestone powder applied to seed at the rate of two or three ounces per bushel is almost as effective as copper carbonate in controlling bunt infection. The difficulty of its use lies in the fact that

it may not retain its powdered form because it becomes massed by absorbing moisture. Therefore, if copper carbonate dust is not available, bluestone powder or anhydrous copper sulfate may be used as a fair substitute.

7. Copper carbonate dust applied to seed wheat at the rate of two ounces or more to the bushel effectively controls bunt when the seed is not blackened with spores. For heavily bunted seed, bluestone and formaldehyde solutions are more effective, but are liable to cause severe seed injury.

8. Seed wheat treated with copper carbonate dust is not injured by the fungicide even when held in storage for an indefinite period. This permits the treating of seed during the slack season, thus avoiding loss of valuable time during seeding operations.

9. Germination of seed wheat is not inhibited by copper carbonate dust. Excellent stands usually are secured and less seed required per acre than when fungicidal solutions are used. Seed treated by the standard liquid methods frequently have to be sown 30 to 70 per cent heavier than is necessary for copper carbonate-dusted seed (table 9).

10. Seed treated with copper carbonate dust germinates earlier and makes a more vigorous seedling growth than seed treated with fungicidal solutions. Prompt emergence from the soil and early root development combined with a superior stand are usually reflected in an increased yield.

11. Dilution of copper carbonate dust does not appear to be warranted because: (1) only a limited quantity can be retained upon the surface of the seed (less than two ounces per bushel); (2) diluted copper carbonate dust applied at two ounces per bushel is not completely effective in bunt control; and (3) dilutions may favor poor processes in manufacture, resulting in inferior bunt control (table 6).

12. The best standard for effective copper carbonate dust appears to be as follows:

> Copper in the form of copper carbonate (52 to 54 per cent) and copper hydrate (39 to 42 per cent), totaling 93 to 94 per cent of these two, with impurities amounting to 6 or 7 per cent of the whole mass.
>
> Fineness: Ninety-nine per cent in aqueous solution should pass through a 200-mesh sieve.
>
> Density after shaking down dry: not over 32 lbs. per cubic foot.
>
> Color: light green, never blue.

13. Copper carbonate dust when inhaled causes nausea and other forms of irritation. These inconveniences can be avoided by wearing a dust mask as prescribed by law for workers in factories producing this and other chemical dusts. A wet sponge or wet handkerchief tied over the nose and mouth will give considerable relief.

14. A serious drawback to the extension of the copper carbonate dust treatment lies in the limited supply of the chemical. It may be imported, but it is then likely not to comply with the standards of fineness and purity demanded. A limited number of factories are now producing satisfactory copper carbonate dust in the San Francisco bay region.

15. The price of copper carbonate usually is more than double that of bluestone. As copper carbonate contains more than double the amount of copper (52–55 per cent) contained in bluestone (25.04 per cent), from which it is made, this ratio is not unreasonable. However, the saving in the cost of labor with the dust treatment is many times greater than this difference in price.

16. The greatest obstacle to the universal adoption of copper carbonate dust lies in the lack of proper machinery to dust economically and effectively large quantities of seed in a short time. This difficulty is rapidly being overcome by the invention of automatic dusting machinery. This machinery should properly become part of the local warehouse or elevator where seed may be cleaned, graded and dusted at one operation, and stored ready for use.

17. A few reports unfavorable to the use of copper carbonate have come from other regions,[16] but in the great majority of instances the reports have been very satisfactory. Reports are now available from Australia, Canada, Denmark, Italy, and several parts of the United States.[5, 13, 19, 25]

18. Organic mercuric fungicides, usually consisting of chlorphenol-mercuric compounds in varying porportions, have been found to be excellent bunt preventives without germ injury when used as solutions, but less effective when applied as dusts. These compounds: Chlorophol,[12, 27, 28] Seedosan, Germisan, etc., are not readily available and are apparently very expensive.

19. All seed wheat should be treated every year because a slight quantity of bunt spores may cause wholesale infection, as each bunted kernel or gall contains from one to eight million spores.[4]

LITERATURE CITED

[1] BARSS, H. P. Results of tests with copper carbonate. Harvest of 1922. Preliminary Report. Oregon Agric. Exp. Sta., Circ. 30. August 10, 1922.

[2] BOLLEY, H. L. The use of the centrifuge in diagnosing the plant diseases. Proc. Soc. for the Prom. of Agric. Sci., 23:82–85. 1902.

[3] BOLLEY, H. L. New work upon the smuts of wheat, oats, and barley, and a resume of the treatment experiments for the last three years. No. Dak. Agric. Exp. Sta. Bull. 27. 1897.

[4] COBB, N. A. Quantitative estimation of bunt spores in seed wheat. Agric. Gazette, New South Wales, 16:1113–1117. 1905.

[5] COONS, G. H. Copper-dust treatment for stinking smut. Michigan Quarterly Bull., 5:1, pp. 8–11. August, 1922.

[6] DARNELL-SMITH, G. P., and CARNE, W. M. Effect of formalin on germination of plants. In 3rd Rept. Gov't. Bull. Microbiol. N. S. W. 1912.

[7] DARNELL-SMITH, G. P. The use of copper carbonate as a fungicide. Agric. Gazette, N. S. W., 26 (1915), No. 3, p. 242.

[8] DARNELL-SMITH, G. P. The prevention of bunt. Experiments with various fungicides. Agric. Gazette, N. S. W., 28:185–189. March 2, 1917.

[9] DARNELL-SMITH, G. P., and ROSS, H. A dry method of treating seed wheat for bunt. Agric. Gazette, N. S. W., 30:685–692. 1919.

[10] DARNELL-SMITH, G. P. Fungicidal dusts for control of smut. Agric. Gazette, N. S. W., 32:796–798. 1921.

[11] DARNELL-SMITH, G. P. Dry copper carbonate for bunt. Agric. Gazette, N. S. W., 33 (1922), No. 10, pp. 754–755.

[12] HEALD, F. D. Div. of Plant Pathology. Wash. Coll. Sta. Bull. 167 (1922), pp. 38–43.

[13] HEALD, F. D., and SMITH, L. J. The dusting of wheat for bunt or stinking smut. Wash. Agric. Exp. Sta. Bull. 168, p. 15. June, 1922.

[14] HEALD, F. D., and SMITH, L. J. The dusting of wheat for bunt or stinking smut. Wash. State Coll. Agric. Exp. Sta. Bull. 171. October, 1922.

[15] HEALD, F. D. The relation of spore load to the per cent of stinking smut appearing in the crop. Phytopath., 11:269–278. 1921.

[16] HUNGERFORD, C. W. The News Letter. The University of Idaho. Published by the College of Agric. Vol. 8, No. 8. September 25, 1922.

[17] HURD, ANNIE MAY. Injury to seed wheat from drying after disinfection with formaldehyde. Jour. Agric. Res., V, No. 3. November 1, 1920.

[18] HURD, ANNIE MAY. Seed-coat injury and viability of seeds of wheat and barley as factors in susceptibility to molds and fungicides. Jour. Agric. Rec., Vol. 21, No. 2. April 15, 1921.

[19] KÜHN, J. G. Krankheit die Kulturgewächse, p. 85, 1859.

[20] LAMBERT, E. B., and BAILEY, D. L. Results of treating seed of spring wheat and oats with copper carbonate dust to prevent smut. Phytopath., 12. 1922.

[21] MACKIE, W. W. Seed treatments for the prevention of cereal smuts. Cal. Exp. Sta. Circ. 214. September, 1919.

[22] MACKIE, W. W., and BRIGGS, F. N. Fungicidal dusts for control of bunt. Science, n.s., Vol. 52, No. 1353, pp. 540–541. December 3, 1920.

[23] MACKIE, W. W., and BRIGGS, F. N. Chemical dusts for the control of bunt. Phytopath., 11:38–39. 1921.

[24] MCLEOD, GEORGE R. Control of smut. Agric. Dept., Sperry Flour Co., Stockton, Calif. November 18, 1921.

[25] MORETTINI, A. Sulla efficacia dei trattamenti polverulenti contro la "carie" del frumento. (Efficiency of powders for controlling smuts of cereals.) Trans. by Theo. Holm. Stoz. Sperim. Agric. Ital., Vol. 54, pls. 7–10 (Modena), pp. 293–315. 1921.

[26] PERKINS, A. J. Random agricultural jottings. Jour. Dept. Agric. So. Africa, 23:287–290. 1919.

[27] RIEHM, E. Prüfungeiniger Mittel zur Bekämpfung des Steinbrandes. (Experiments with some fungicides to combat bunt, or stinking smut.) Trans. by Theo. Holm. Nitth. aus d. Kais. Biol. Aust. f. Land. u. Forstwiss. Noft. 14, Berlin, pp. 8–9. 1913.

[28] REMY, TH., and VASTERS, J. Beobachtungen ueber chlorphenol-quecksilber als Pflanzenschutzmittel. (Observations on Chlorphenol-Mercury as a Fungicide.) Trans. by Theo. Holm. Illust. Landwirt Zeitung, 34th year, Berlin, 1914, pp. 769–771.

[29] TUBEUF, VON REG. RATH, DR. FREIHERR. Studien ueber die Brandkrankheiten des Getreides und ihre Bekämpfung. Mit 1 Tafel (VIII) und 19 Testfiguren Arbeiten aus der Biologischen abcheilung für Land- und Forstwithschoft am Kaiserl. Gesundheitsamte. II pt. 4, Berlin. 1902.

[30] WHEELER, W. A. Preliminary experiments with vapor treatments for the prevention of the stinking smut of wheat. So. Dakota Agric. Coll. Exp. Sta. Bull. 89. November, 1904.

[31] ZUNDEL, GEORGE L. Summary of copper carbonate treatment for the control of smut. State of Washington 1922 Crop. Wash. Agric. Exp. Sta. August 2, 1922.

Fig. 12.—No. 3, bunted Propo head and bunt gall. No. 4, normal Propo head and kernel. When bunted plants are supplied with an excess of space, light, moisture and plant food, the disease may stimulate excessive growth as indicated here.

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